Fermi National Accelerator Laboratory

FERMILAB-Pub-78/25-EXP
7340.026
(Submitted to Phys. Rev. Lett.)

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February 1978

Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration

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MSU-CSL-52

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Abstract

It is plausible that (a) multimuon events observed in deep inelastic muon scattering are manifestations of associated charmed meson production and (b) the latter is responsible for a sizable fraction of observed scaling violations at small values of the scaling variable x.

During the past few years, systematic departures from scaling have been observed both in muon and electron scattering experiments.[1-3] With increasing q^2 (square of momentum transfer), the nucleon structure function νW_2 rises at small $\underline{x}$ and falls at large $\underline{x}$ ($\equiv q^2/2M\nu$ with M the nucleon mass and ν the energy of the virtual photon). This pattern of scale violations has been compared with theoretical predictions either phenomonological[4] or derived from the quark structure of the nucleon.[5]

The production characteristics of dimuons ($\mu N \to \mu\mu N$) and trimuons ($\mu N \to \mu\mu\mu N$) observed in 150 GeV deep inelastic muon-nucleus scattering were described previously.[6] It was shown that 85% of the observed dimuons were unaccounted for by well-established mechanisms. The total of eight kinematically fully reconstructed trimuons can be divided into five "quiet" (inelasticity, $\eta < 0.2$) and three inelastic ($\eta > 0.2$) events. The main trimuon backgrounds are assumed to be direct pair production (electromagnetic tridents) and production of vector mesons, especially ϕ because of its large (7%) $\mu\mu$ decay branch. Their total contribution is crudely estimated to be one trimuon (about 0.75 inelastic and 0.25 elastic events).

Since the experiment is biased towards detecting events at large transverse momentum, an obvious mechanism for producing the extra muons is via associated production and decay of heavy particles. Among many possible muon progenitors the charm carrying D-meson appears the most likely candidate. The D-meson origin of the muons has already been suggested by several authors[7,8] along with brief analyses. The motivation of the present work is to (a) treat multimuon detection efficiencies realistically, (b) include inelastic trimuons in the analysis, and (c) study the relation of multimuons and scaling violation.

For any reasonable model of multimuon production, the total detection efficiency of the experiment is small. The rate of multimuon production appears to be more sensitive to the model assumed than is the shape of various kinematical distributions. This is also true of the background.[6] For this reasons a careful treatment of detection efficiencies is essential.[9] Since the scaling violation is most pronounced at small $\underline{x}$, a cut of $0.015 < \underline{x} < 0.075$ has been made. Eighty percent of all dimuons belong to this class as do two of three inelastic trimuons.

The basic model adopted for charmed meson production is that of Bletzacker and Nieh[7] (BN). Because trimuons are of interest the BN formula is made to apply to $D\bar{D}$ pairs rather than to single D production. This differs insignificantly from BN except near threshold, while treating the kinematics more accurately. The production cross section is given by

$$\frac{d^3\sigma}{dxdyd^3\vec{p}} = (8\pi\alpha^2 MEq^{-4})F_{ch}(x,y)f(\vec{p}) \qquad (1)$$

where $\underline{y} = \nu/E$ with E the incident energy; $\vec{p}$ is the momentum of the $D\bar{D}$ pair, α the fine structure constant and M the nucleon mass. The structure function $F_{ch}(x,y)$ is assumed to be

$$F_{ch}(x,y) = A[q^2/(q^2+4M_D^2)][(s-s_o)/s]^3 e^{-10x'}[1+(1-y)^2] \qquad (2)$$

where A is a normalization factor, M_D = 1.86 GeV, s is the square of the invariant mass of the virtual photon-nucleon system, s_o is the threshold s for $D\bar{D}$ production and $\underline{x}' \equiv (q^2 + 4\ M_D^2)/2\ M\nu$. The inclusive $D\bar{D}$ momentum distribution is taken to be

$$f(p) = Ne^{-az}e^{-bp_T^2} \qquad (3)$$

where N is a normalization factor, $z \equiv p_z/\nu$ with p_z the longitudinal and p_T the transverse $D\bar{D}$ momentum (as noted above, in BN z and p_T refer to a single D). The parameters $\underline{a}$, $\underline{b}$ are fixed in BN: $\underline{a}$ = 3 and $\underline{b} = (M_D^2 + 0.03q^2)^{-1}$. In this work the weak q^2 dependence of $\underline{b}$ is removed and $\underline{a}$ and $\underline{b}$ are left free. The invariant mass of the $D\bar{D}$ system is chosen from a theoretical distribution of associated production.[10] The decay of $D\bar{D}$ is assumed to be isotropic in the $D\bar{D}$ rest frame. To study trimuon production the correlation between the two D's is kept. The D is assumed to decay[11] into $K^*\mu\nu$ with a 10% branching ratio.

Characteristics of muon production according to the above model are calculated by Monte Carlo and the muons are then traced through the apparatus. Multiple scattering, energy loss, straggling, all relevant detail of target-detector geometry, magnetic fields, scanning criteria, known uncertainties in momentum reconstruction and the $\underline{x}$-cut are included. Figure 1 presents a comparison of the calculated p_T' distribution (of the non-leading muon) with experiment. In Figure 2 the z' distribution is shown where $z' \equiv p_z/\nu$ ($p_z \equiv$ longitudinal momentum of non-leading μ). In both graphs calculation is normalized to the data. With the exception of a few high p_T' - high z' events (they are strongly correlated) agreement is satisfactory.

In both Figures 1 and 2 the choice of parameters is $\underline{a} = 1$, $\underline{b} = 0.25$. Neither distribution is very sensitive to this choice, although small $\underline{b}$ values are favored by the observed p_T' distribution.[12] Preliminary data from a higher energy experiment[13] also support small $\underline{b}$ by comparing the ratio of dimuons produced at each energy with calculation. This ratio is fairly sensitive to the choice of $\underline{b}$ (it increases by a factor of two from $\underline{b} = 0.25$ to $\underline{b} = 3$) and also favors slightly the lower values of $\underline{a}$. The calculation predicts a (2μ/3μ) ratio of 25 which is quite insensitive to the parameters and is well above the observed ratio of 10 ± 6.

By using the observed dimuon rate to normalize BN predictions, an estimate is made of the increment in the structure function, νW_2. The $\underline{x}$ cut isolates the small $\underline{x}$ region where scaling violation is most prominent. In Figure 3 the contribution to the scaling violation[14] is plotted as a function of $\underline{a}$ for values of $\underline{b} = 0.25$ and $\underline{b} = 3$. If multimuons are indeed manifestations of charm one must then conclude that associated charm production is likely a sizeable component of the scaling violation at small $\underline{x}$.

Other variants of the model are possible,[15] besides those illustrated in Figure 3. The present analysis concerns only the dominant member of a set of related process, e.g. D decays to different final states such as $K\mu\nu$, $n\pi K\mu\nu$, etc. and associated charmed meson-baryon production. Based on simple total cross-section estimates, production of charged or neutral heavy leptons and associated bottom quantum number carriers are not expected to contribute significantly to the multimuon sample of the present experiment.

It is a pleasure to acknowledge useful discussions with E. Lehman and H. T. Nieh.

*Work supported in part by the National Science Foundation under Grant No. GP29070 and by the United States Department of Energy.

†On sabbatical leave at Fermi National Accelerator Laboratory, 1977-1978.

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13. K. W. Chen, in Proc. 1977 Int. Symp. on Lepton and Photon Interactions at High Energies, Hamburg, Germany, (Aug., 1977).

14. The observed $\Delta(\nu W_2)$ in Figure 3 is derived by averaging the measure of scaling violation, $(q^2/3)^{(0.25 - x)}$, over the dimuon data.

15. For example, the predicted dimuon rate is also somewhat sensitive to the coefficient of x' in the exponential in (2). Using a value of 8 (also suggested by BN) instead of 10 increases the dimuon rate by about 25% and lowers the predicted scale violation by this same amount. Note also the dependence on the D branching ratio.

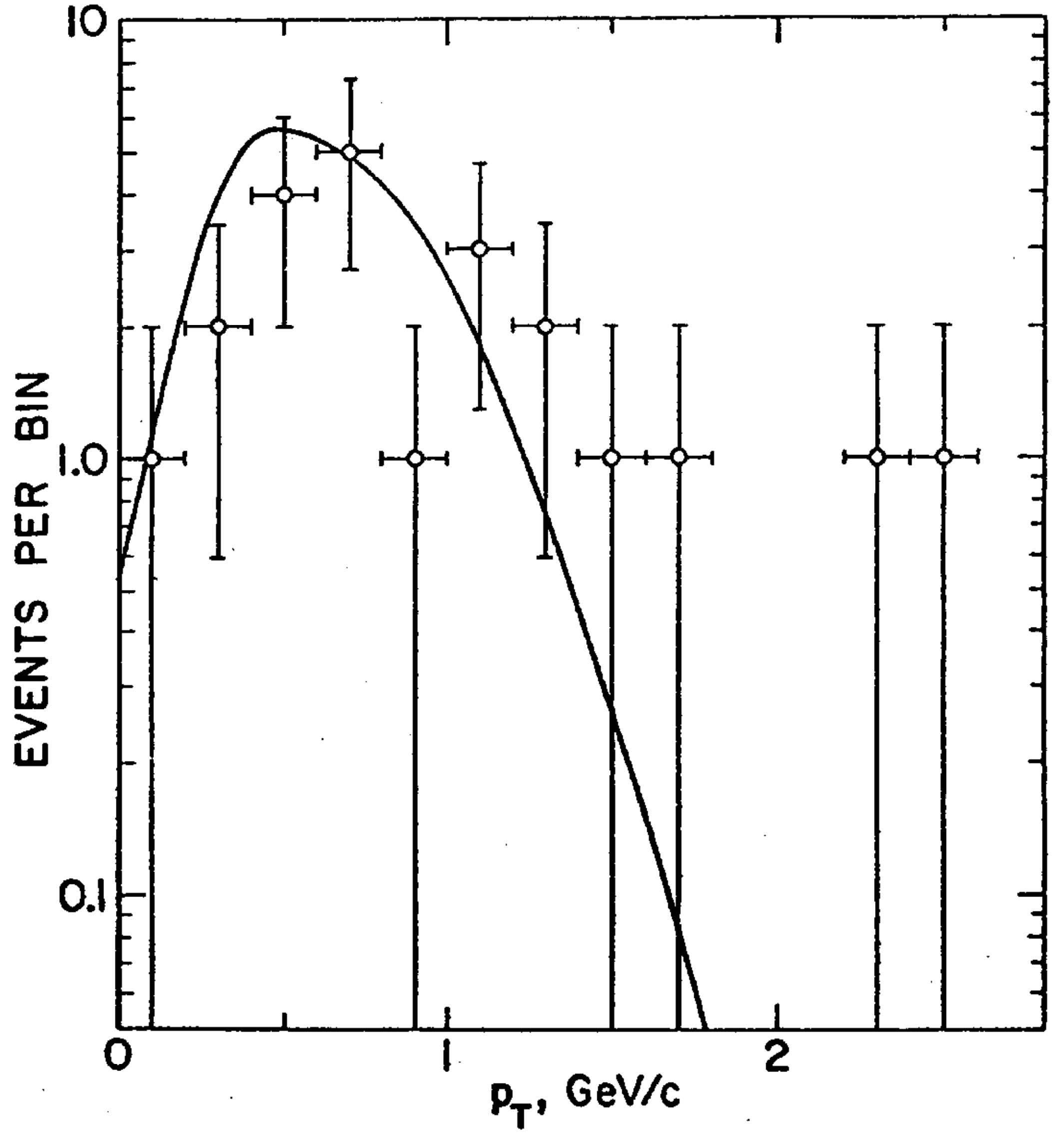

Fig. 1. Transverse momentum distribution for the produced muon with respect to the virtual photon direction. The solid curve is the prediction of an associated charm production model.

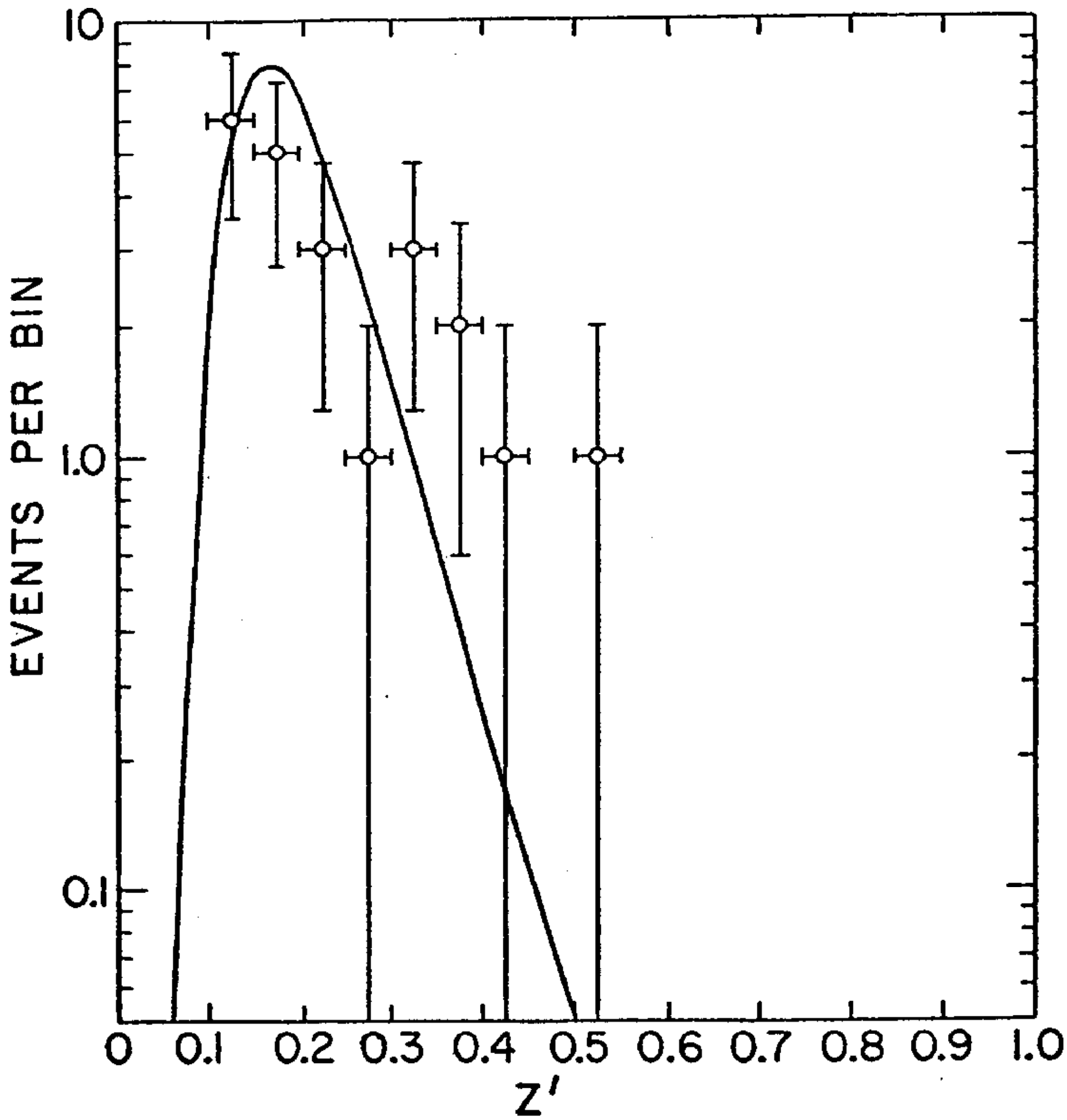

Fig. 2. Distribution of fractional longitudinal momentum, z'. The solid curve is the prediction of an associated charm meson production model.

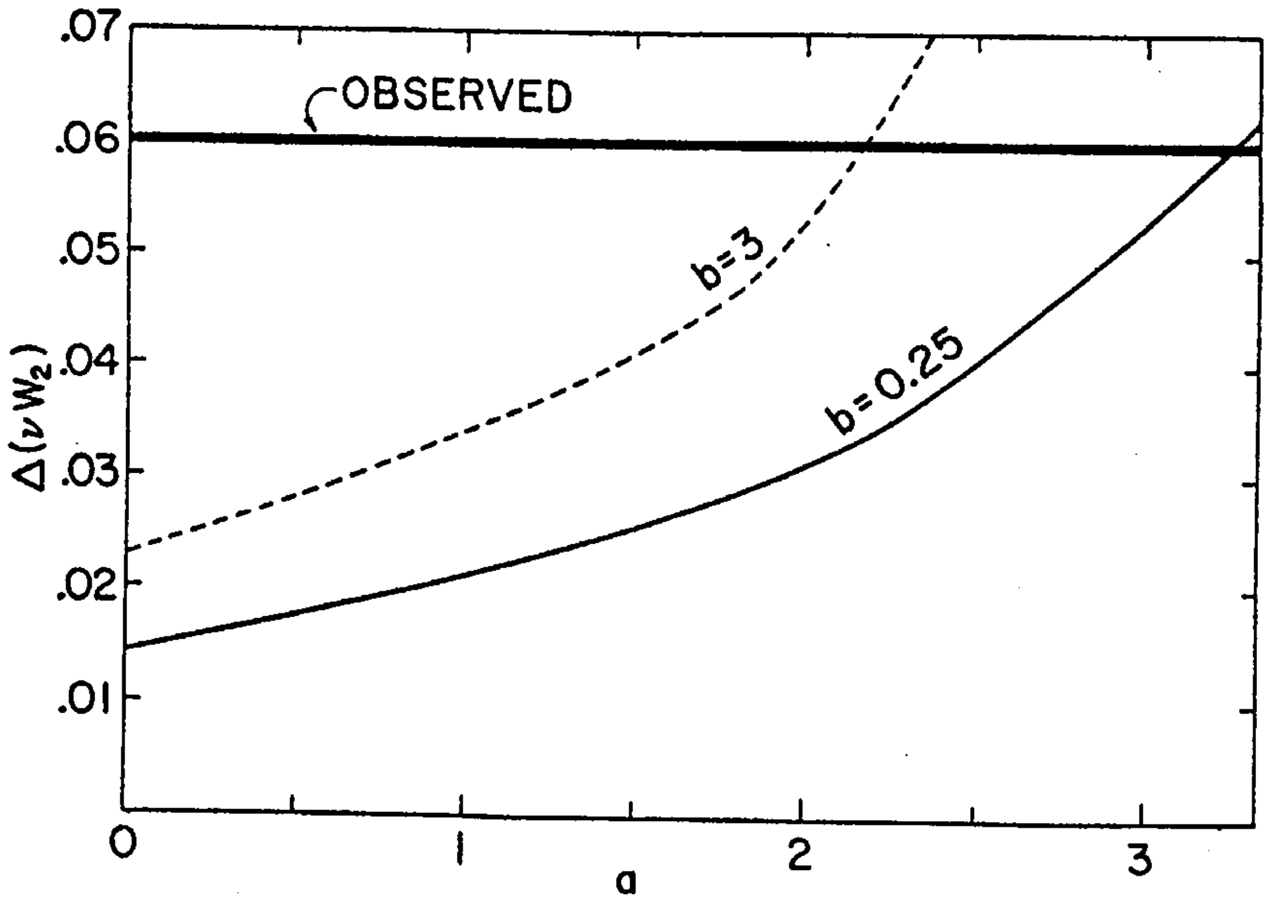

Fig. 3. Average increment in the structure function νW_2 $(0.015 < \underline{x} < 0.075)$ due to associated charm production. The observed scaling violation is shown as a heavy horizontal line. The sensitivity of the parameters used in model to predict the increment is shown. Small values of $\underline{a}$ and $\underline{b}$ appear favored by the analysis.